Using Magnetic Forces to Convey State Information: an Exploration of a Haptic Technology

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ABSTRACT
Using magnetic forces to provide haptic information is an area that remains largely unexplored and provides exciting opportunities for interaction that may not otherwise be possible. We present several example applications that illustrate how this technology is well suited to remote site collaboration techniques, conveying state information and simulating flows and turbulence. Furthermore, we present the results of our preliminary user study which has indicated that magnetic forces can convey two states of information to the user with 100% accuracy, and can convey three states with 89% accuracy.

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Haptics, user interaction, touch interaction

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H5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

INTRODUCTION
Haptic technologies, such as the Phantom device (Massie, 1994), have been focused on generating kinesthetic information. Kinesthetic information is gathered by sensors in the muscles, tendons and joints, and allows us to feel motion and forces. Cutaneous information is gathered by receptors beneath the skin and conveys information relating to pressure, temperature and pain (Oakley et al., 2000). Importantly, we also use cutaneous information to feel textures (Lederman et al., 1996). A study by Oakley et al. (2000) found that cutaneous information is difficult to create with devices such as the Phantom. We believe that the generation of cutaneous information could be better achieved with magnetic forces. The Phantom device has only a single point of contact, providing a single force vector at that point. This has been described as a huge bandwidth reduction when considering the body's haptic ability (Yu et al., 2001). Magnetic forces can provide haptic feedback beyond just fingertip interaction by using an untethered magnetic stylus or glove to give a full hand haptic experience. Furthermore, augmenting a touch surface with electromagnets allows the user's hand to be rested upon a surface when interacting, rather than extended as it is when using the Phantom. Thus, magnetic forces can provide many advantages.

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Electromagnets arranged in a grid formation have been used to enable human-computer interaction techniques in the past, including object actuation applications (Pangaro et al., 2002; Weiss et al., 2010) and applications involving magnetic fluid (Hook et al., 2009; Koh et al., 2011). However, we have identified that using a grid of electromagnets as a haptic technology remains largely unexplored. One such application is MudPad (Jansen et al., 2010), which consisted of a pouch of magnetic fluid that was used as a touch surface and a display surface. The fluid was able to be stiffened using an underlying grid of electromagnets and the resulting change of viscosity was used to provide haptic feedback. FingerFlux (Weiss et al., 2011) used a grid of electromagnets and a magnet attached to a user's finger to provide interaction techniques such as guiding a user's button presses. We believe that magnetic forces should be explored further as a haptic technology, as there are exciting opportunities for interaction that may not be possible with other technologies.

We present novel magnetic force interaction techniques, many of which have been motivated by the Phantom device. We envisage that magnetic force interaction is well suited to table top applications. Furthermore, we show promising preliminary results indicating that magnetic force interaction can successfully convey state information to users.

MAGNETIC FORCE INTERACTION
We envisage that a user may walk up to a touch surface, pick up a magnetic stylus, and be able to feel forces pushing and pulling the stylus as they interact with the surface. From our preliminary testing, we feel that the stylus as an input device is suitable for this technology. We prefer a stylus rather than attaching a magnet to a user's finger as demonstrated previously (Weiss et al., 2011), as we view the latter as being cumbersome and not suited to real world scenarios. We feel that a finger being held outstretched and touching a surface has many muscles making a relatively rigid structure to impart force, whereas a hand holding a stylus is perhaps a more relaxed state with smaller muscles moving it and so able to detect resistance and attraction at a finer level.

Vibrotactile technologies are commonly employed to allow touch surfaces to gain tactile abilities, however magnetic force interaction differs from this. A user may receive notifications of a change using vibrotactile techniques; however, magnetic forces assume the opposite behaviour. The touch surface waits passively and the user assumes the active role, initiating an exchange of information by touching the device. Opportunities exist to capitalise on the advantages of the passive nature of this technology. These advantages are similar to those of texture displays (Harrison et al., 2009) and are present in scenarios that require persistent information, and when users want to initiate the interaction, which cannot be easily achieved with vibrotactile techniques.

We are in the process of implementing a system comprising of a grid of computer controlled electromagnets. This system will have an interchangeable horizontal surface able to support both an LCD display and a blank surface. The former allows reinforcement of the information conveyed via magnetic forces and the latter allows for experimentation involving private information, and the easing of the user's visual channel. Our initial tests have not shown any adverse effects to an LCD display by having magnetic forces pass through it for a prolonged period of time; however, we intend to test this further.

EXAMPLE APPLICATIONS

We describe some magnetic force interaction example applications that we would like to explore further.

Conveying State Information

Our preliminary user study outlined in this paper indicates that magnetic forces can be used to convey state information. For example, a user interacting with a touch table can be undertaking another task such as editing a document, whilst waiting for a file to download. The magnets can provide a sensation to convey the state of the download to the user, while the user is editing the document. This stream of information can be easily stopped by simply putting down the stylus. Thus it would be less intrusive than vibration, audio cues and visual cues, and better localised at particular points. However, it may also be possible to produce a magnetic force that is strong enough to prevent the user from continuing with their work, to force the user's attention to the other task. Another example would be to fit a wall of a house with an electromagnetic grid, so that a person wearing gloves embedded with magnets can run their hand along the wall on the way to their car, to check the status of their security system. This technique is useful for a range of scenarios where it is important not to overload the user with visual items, or when privacy or simplicity is required.

Touch Table Interaction

Magnetic forces can be used to implement exciting new metaphors for touch table interaction. For example, in distributed collaborative systems such as the Blended Interaction Space (Broughton et al., 2009), users are able to collaborate with other users at a remote site. A touch table is present at each site to aid with this collaboration, as well as four screens, two of which offer a shared desktop and the other two allow for video teleconferencing (VTC) capabilities. A user manipulating a file at the local site using the touch table and a magnetic stylus would like to send the changed file to the remote site. The user can drag the item to a virtual opening, and push the item through, allowing it to appear at the remote site. A magnetic force would be present at the opening, which decreases in strength as the document is moved to the remote site – simulating the feeling of squeezing an object through an opening to have it appear at the other side. This technique can be coupled with remote guidance at remote sites, which is an idea that Weiss et al. (2011) also mentioned for their FingerFlux system. In our scenario, after the user has pushed the item through to the remote site, the user could guide the remote user's magnetic stylus movements to retrieve the document, and to draw the remote user's attention to a part of it.

Simulating Flows, Turbulence and Textures

As described, we feel that magnetic force interaction is well suited to simulating cutaneous information pertaining to touch, pressure and textures. We would like to explore the interactive simulation of facets of fluid mechanics, particularly fluid kinematics and fluid dynamics, which relate to fluids in motion and the effect of forces on fluids in motion. Furthermore, we are experimenting with methods of simulating texture using magnetic force interaction, which we feel is an exciting application.

EVALUATION

A user's ability to discriminate between different strength magnetic forces is important as it can serve as a basis for many interaction techniques. There is scope for more experimentation in haptics (Oakley et al. 2000) and we have decided to first investigate how much information could be conveyed to users by magnetic forces alone.

Weiss et al. (2011) determined that users were able to press two buttons more accurately with the assistance of magnetic forces. They also determined that, within their system, users are able to feel the magnetic force 35mm above the surface of the table when their magnet endowed finger is lifted to a height. However, their scenario is static and the sensation may feel different when the user is dynamically interacting with the magnetic force. We would like the user to interact with a magnetic force and differentiate between different states, represented by different strengths of the magnetic force. We feel this is a real world scenario and the basis of many possible interaction techniques.

Experiment Design

The aim of our preliminary user study is to determine whether state information can be conveyed using magnetic forces, and if so, how much information. Our study is loosely based on the study undertaken by Harrison et al. (2009). The states are different repulsive strengths of a magnetic field. To simplify our evaluation, we used one electromagnet of 20mm diameter and length of 50mm, using 0.80mm gauge copper wire wound in 507 turns, which has 0.40ohms of resistance. This is approximately the footprint we are looking to use for our computer controlled grid implementation. Both FingerFlux (Weiss et al., 2011) and the Actuated Workbench (Pangaro et al., 2002) use similarly sized electromagnets.

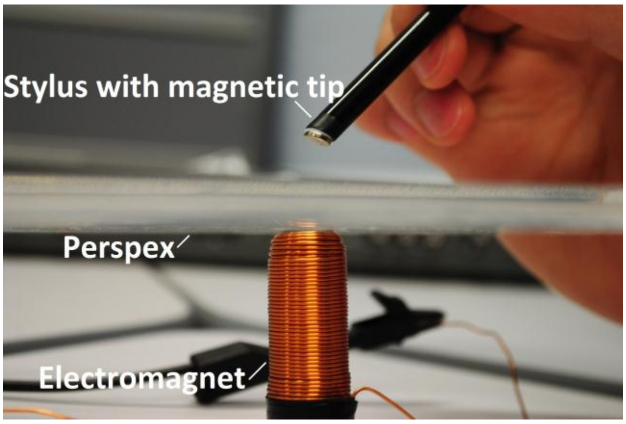

Figure 1 Preliminary user study setup. The Perspex represents the thickness of an LCD display.

As shown in Figure 1, the magnet is placed underneath a sheet of 7mm thick Perspex. This thickness represents a typical LCD panel to simulate the display surface that our final implementation will have. For this preliminary study we opted to use a prototype magnetic stylus consisting of a stylus with a neodymium magnet of 7mm diameter and 2mm thickness attached to the tip. A final implementation would include a refined magnetic stylus that has been designed to prevent scratching the surface upon which it is used.

The user was asked to use the magnetic stylus to interact with the area of the Perspex surface above the electromagnet. The magnet is set to different strengths, which we refer to as states, and the user is asked to recall the name of the current state. Electromagnets are large in size and have a power requirement that makes them less suitable for mobile devices. Hence we have focused on horizontal interaction surfaces, as we envisage magnetic force interaction to be better suited to large touch surfaces such as touch tables and mounted displays. Although simple, this study is sufficient to answer the central question of whether or not magnetic forces can be used to convey state.

We recruited a total of 14 participants (10 males, 4 females) with a mean age of 25 years. The study took approximately 40 minutes. Four participants completed a two state version of the experiment, and ten participants completed a three state version. The two state version involved the magnet being powered with 0 Amps and 7 Amps (3.9 volts) to represent states 1 and 2. The three state experiment used 0 Amps, 3.5 Amps (1.9 volts) and 7Amps (3.9 volts), which represented states 1, 2 and 3 respectively.

Each participant interacted with each of the states in order, and then completed a training set where each state was presented to the participant three times, in a random order. The user was able to interact with the force of each state, then verbalised what they thought the current state was, and was told whether their response was correct or incorrect. Following the training set, the participant completed three sets where each of the states was presented eight times, in a random order, and was not given any feedback regarding whether their answer was correct. After verbalising the state, the participant was asked to return their hand to a zone located away from the magnetic force, before the power was adjusted for the next state. Hence, we are measuring whether the user can determine the state with the stylus removed between states, as opposed to keeping the stylus in place and feeling the sensation of the power ramping up or down, or staying constant. We chose this option as we felt it would be more applicable to real world situations: the user may not keep their stylus in the same place waiting for the next state change. Instead, the user may remove the stylus or do another task in the meantime. We have performed some further preliminary studies which indicated that results are less accurate when the user keeps the stylus in place for the change in power.

RESULTS AND DISCUSSION

We present results for the two state and three state versions of the experiment. Participants were able to complete the two state experiment with 100% accuracy, and all participants labelled the task as being either easy (75%) or very easy (25%). Participants were still able to achieve high levels of accuracy in the three state experiment, with users correctly naming the state in 89% of all cases. State 1 was the most accurately named state, being named correctly 97% of the time. This was followed by state 2 with 89% and state 3 with 82%, as illustrated in Figure 2.

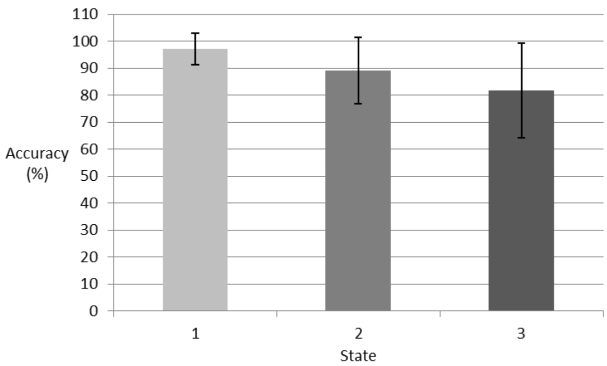

Figure 2 Accuracy for each state (three state experiment)

Further analysis shows that 57% of all incorrectly guessed states were actually state 3, 34%, were state 2, and 9% were state 1. Several participants commented that it was difficult to tell the difference between state 2 and state 3. Several participants commented that it was easy to determine State 1, as it was off and therefore felt different from the other states. These assertions may explain the increased proportion of incorrect answers for state 3 and the decreased proportion of incorrect answers for state 1.

The results of the three state version of the experiment also indicate that, of the incorrectly guessed states, 71% were guessed one state too low by the participant, and the remaining 29% were guessed one state too high. It can also be noted that 45% - almost half – of the incorrect answers occurred as a string of incorrect answers. This indicates that perhaps participants were using the previous state as a comparison for the next state, and therefore could be more likely to be wrong again if they had the previous state incorrect. No participant got the state wrong by more than one state. For example, no participant stated State 3 as their answer when the correct answer was State 1. This was the case for all versions of the experiment.

Participants indicated how difficult they felt the task was on a five point Likert scale, ranging from very easy to very difficult. For the three state task, participant responses gave an average of 2.5, with most participants choosing either easy or neither easy nor difficult, and no participants indicated that the task was very difficult. Several participants commented that the magnetic force felt different if they held the stylus with a different grip partway through the experiment, which is something that user interface designers may have to consider.

These promising results indicating that state conveyance using magnetic forces is plausible. We would like to see it integrated in applications such as the example applications we have described. However, it may be beneficial to perform further research and analysis, to address the numerous trends identified by these results. In particular, it would be interesting to determine whether a distractor task impacts the number of states detectable.

CONCLUSIONS

It is evident that the area of using magnetic forces to provide haptic information is largely unexplored and provides exciting opportunities for interaction that may not otherwise be possible. We see magnetic force interaction as having the potential to be highly successful in conveying cutaneous information to the user, thus allowing texture information to be rendered more accurately in virtual worlds. We have presented several example applications which demonstrate the usefulness of this technology in the areas of remote site collaboration, conveying state information and simulating flows and turbulence. Furthermore, our preliminary user study has indicated that magnetic forces can convey two and three states to the user with high levels of accuracy.

FUTURE WORK

We would like to explore a four state experiment as the two and three state experiment results have been encouraging. There are plans to undertake further analysis of the data gathered in our preliminary study. We would like to analyse user's recognition of a state based on the previous state experienced. We would also like to explore different interaction scenarios – such as the user having their hand move over a magnetic field in a 'fly by' manner, with different angles of approach, to better simulate certain real world scenarios. Although we feel that a stylus is a more suitable interaction device compared with attaching a magnet to the user's finger, we would like to undertake a study to ascertain this.

We are currently implementing a computer controlled grid of electromagnets to allow us to further explore magnetic force interaction, implement the example applications and perform more in depth user studies. Simulation of the system indicates that, although the electromagnets are limited in size due to the desired resolution, a steel sheet underneath the electromagnets may increase the magnetic forces obtained through the linking of magnetic flux.

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